EXHIBIT
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Gorrell et al.

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(45) **Date of Patent: Apr. 15, 2008**

(54) **COUPLING ELECTROMAGNETIC WAVE THROUGH MICROCIRCUIT**

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G02B 6/36 (2006.01)
G02B 6/02 (2006.01)
H01S 3/08 (2006.01)

(52) **U.S. Cl.** **385/14**; 385/31; 385/89; 385/129; 372/92

(58) **Field of Classification Search** 385/129, 385/14

See application file for complete search history.

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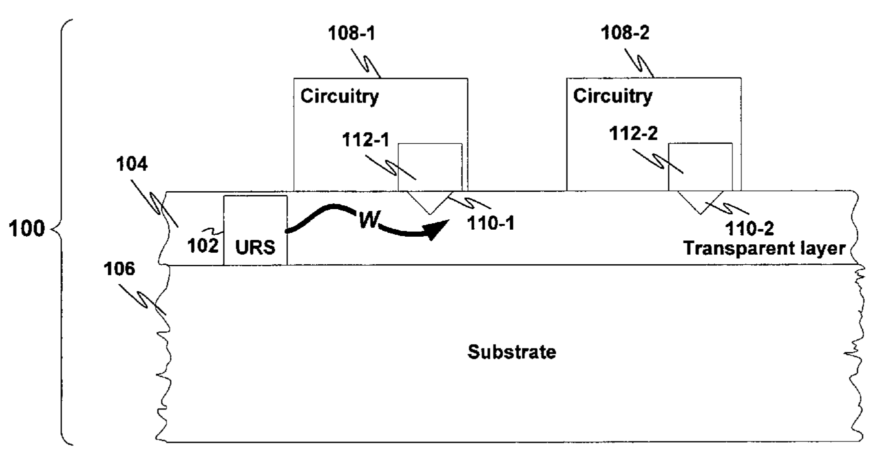
(57) **ABSTRACT**

A device includes a waveguide layer formed on a substrate. An ultra-small resonant structure emits electromagnetic radiation (EMR) in the waveguide layer. One or more circuits are formed on the waveguide layer and each operatively connected thereto to receive the EMR emitted by the ultra-small resonant structure. The waveguide layer may be transparent at wavelengths corresponding to wavelengths of the EMR emitted by the ultra-small resonant structure. The EMR may be visible light and may encode a data signal such as a clock signal.

23 Claims, 3 Drawing Sheets



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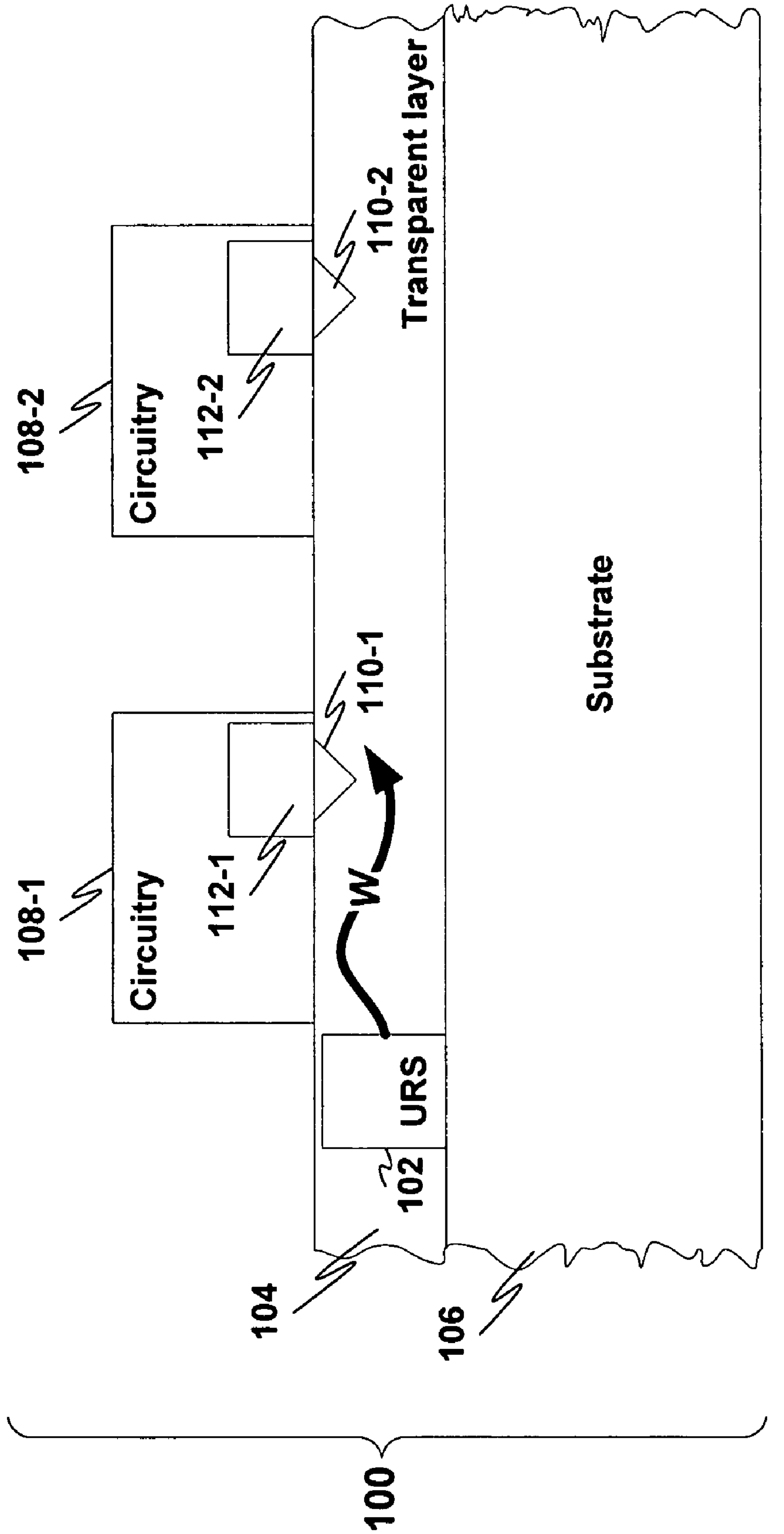
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Fig. 1

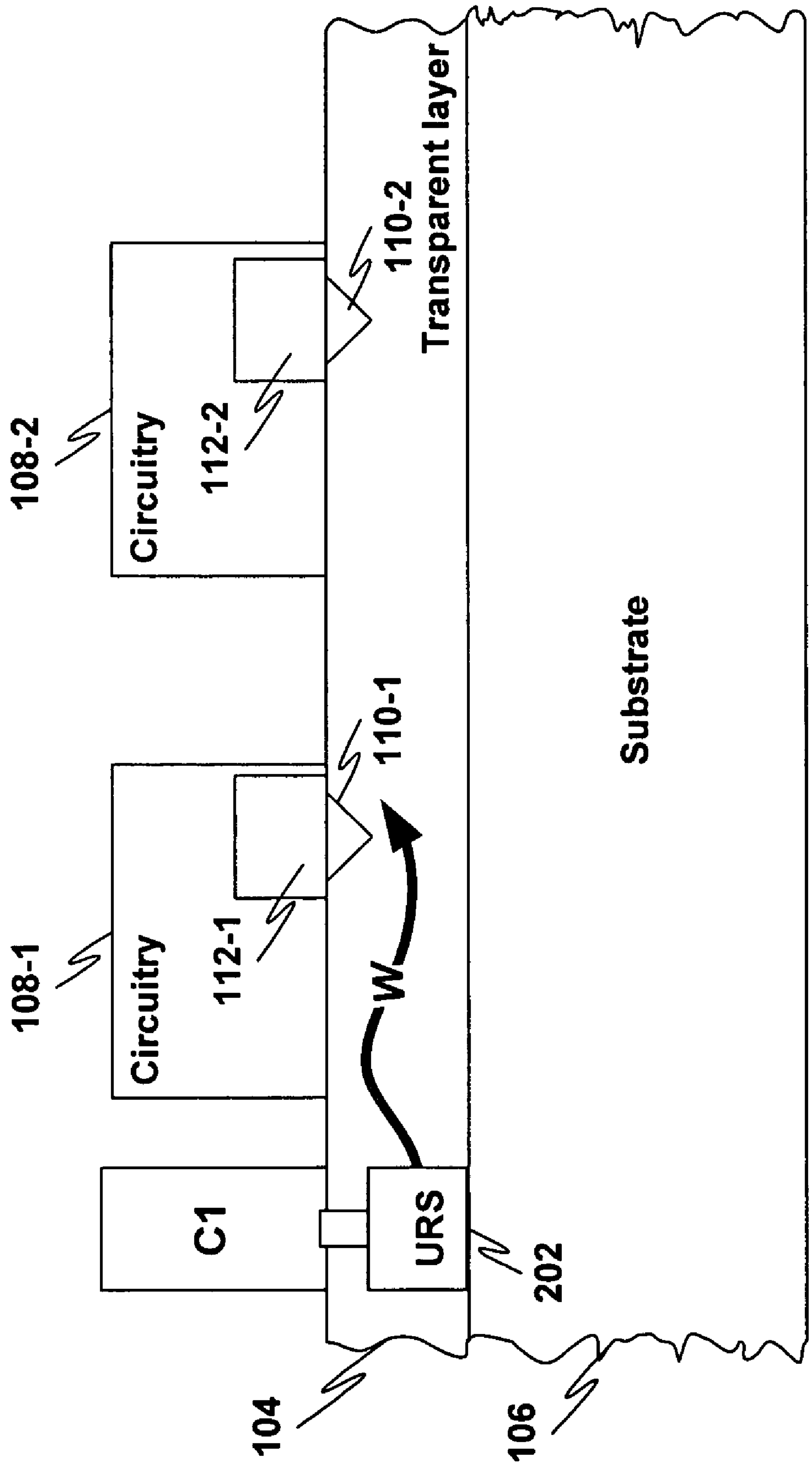
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Fig. 2

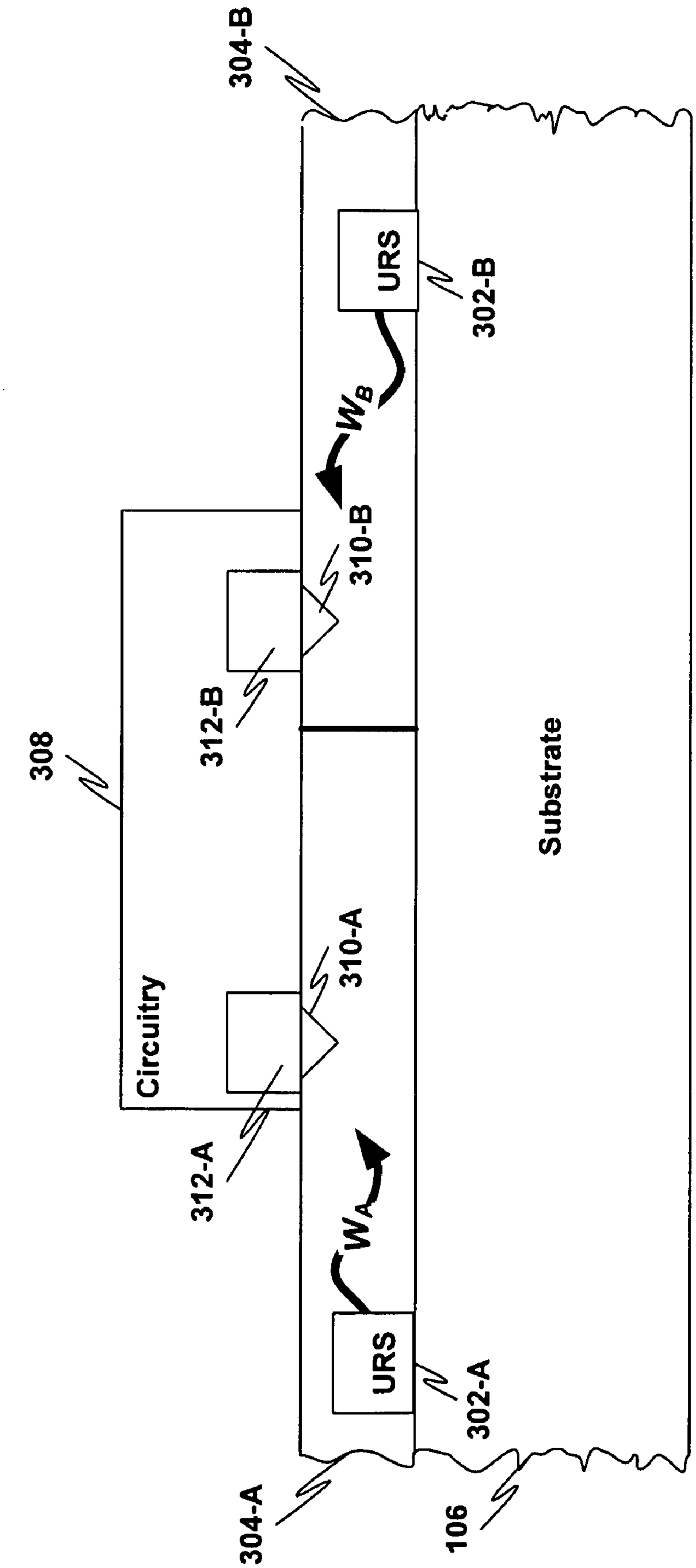
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Fig. 3

COUPLING ELECTROMAGNETIC WAVE THROUGH MICROCIRCUIT

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RELATED APPLICATIONS

The present invention is related to the following co-pending U.S. patent applications, each which is commonly owned with the present application at the time of filing, and the entire contents of each of which are incorporated herein by reference:

1. application Ser. No. 10/917,511, filed on Aug. 13, 2004, entitled "Patterning Thin Metal Film by Dry Reactive Ion Etching";
2. application Ser. No. 11/203,407, filed Aug. 15, 2005, entitled "Method of Patterning Ultra-Small Structures,"
3. application Ser. No. 11/243,476, filed Oct. 5, 2005, entitled, "Structures and Methods for Coupling Energy from an Electromagnetic Wave";
4. application Ser. No. 11/243,477, filed Oct. 5, 2005, entitled, "Electron Beam Induced Resonance";
5. application Ser. No. 11/238,991, filed Sep. 30, 2005, entitled, "Ultra-small resonating charged particle beam modulator";
6. application Ser. No. 11/302,471, filed Dec. 14, 2005, entitled, "Coupled Nano-Resonating Energy Emitting Structures";
7. application Ser. No. 11/325,432, filed Jan. 5, 2006, entitled, "Resonant Structure-Based Display";
8. application Ser. No. 11/325,448, filed Jan. 5, 2006, entitled, "Selectable Frequency Light Emitter";
9. application Ser. No. 11/325,571, filed Jan. 5, 2006, entitled, "Switching Micro-Resonant Structures by Modulating a Beam of Charged Particles"; and
10. application Ser. No. 11/325,534, filed Jan. 5, 2006, entitled, "Switching Micro-Resonant Structures Using at Least One Director";
11. application Ser. No. 11/400,280, filed Apr. 10, 2006, entitled "Resonant Detector For Optical Signals".

FIELD OF THE INVENTION

This relates in general to semiconductor components and, more particularly, to coupling signals throughout semiconductor components.

BACKGROUND & INTRODUCTION

Semiconductor manufacturers are constantly striving to keep up with applications that require faster speeds for their microprocessors or microcircuits. For example, at clock speeds greater than three gigahertz, a microcircuit can be required to couple signals to billions of transistors. Further, microcircuits are continuing to be used over a variety of applications requiring faster speed including modeling and simulation, games, and internet video processing. It is anticipated that microcircuits having faster speeds will continue to be designed for a broad range of systems such as highly parallel supercomputers, back-end servers, desktop systems, and a number of embedded applications.

The industry has made tremendous strides in reducing the gate delays within individual devices of a semiconductor component or microcircuit. This improvement in device speed is generally limited by the conductors between the devices. The conductors can include heavily doped semiconductor materials or conductive metal strips and are commonly referred to as metallization. Generally, the microcircuit includes a plurality of alternating layers of conductors and insulators or dielectric layers. The velocity of propagation of a signal through the conductor is a function of conductor delay. The delay typically depends on a number of factors including the type of conductor material, operating frequency, length of the conductor, spacing between conductors and the permittivity of the dielectric layers adjacent to the conductor. In one example, the conductors of a synchronous digital circuit are required to carry the clock pulses to thousands of locations on the microcircuit at precisely the same time. As the clock speeds increase, the conductor delays can result in a loss in synchronization such that the microcircuit cannot function correctly. By changing the conductor material from aluminum to copper, manufacturers have been able to reduce the delay of signals through their microcircuits. Further, manufacturers have reduced the permittivity or dielectric constant of the dielectric layers, thereby reducing the capacitance between the conductor and the dielectric layer. For example, materials such as hydrogen silsesquioxane (HSQ), methyl silsesquioxane (MSQ), fluorinated glass, or NANOGLASS™ can aid in lowering the dielectric constant.

As clock speeds further increase, the signal or clock pulse is not completely contained on the conductor. Instead, a portion of the signal travels through the dielectric layer adjacent to the conductor. This exposes the clock pulse to an inhomogeneous media. The clock pulse generally includes a square wave shape and contains various frequency components. Hence, the clock pulse spreads out, smears or becomes dispersed in time, because the various frequency components travel at different speeds through the inhomogeneous media. As the requirements for speed further increase, any improvement in reducing delays by changing the conductor and dielectric layer materials are limited. Further gains in reducing the delay can include a combination of reducing the conductor's length and increasing the cross-sectional area of the conductor. The costs for changing the geometry of the conductor can include more processing steps and push the limits of the statistical capability of the process.

We describe a structure for coupling a signal through a microcircuit. In an example of such a structure, a portion of an interconnect or metallization includes a microstructure for generating an electromagnetic wave. The electromagnetic wave carries a signal and is coupled from the microstructure and throughout the microcircuit using a dielectric layer of the microcircuit.

BRIEF DESCRIPTION OF THE DRAWINGS

The following description, given with respect to the attached drawings, may be better understood with reference to the non-limiting examples of the drawings, wherein:

FIGS. **1-3** show side views of devices/structures for coupling signals through a microcircuit.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

FIG. **1** is a side view of a device **100** in which an ultra-small resonant structure **102** is formed within a non-conductive waveguide layer **104** on a substrate **106**.

In general, the ultra-small resonant structure is one which emits electro-magnetic radiation (EMR) when exposed to a beam of charged particles. The structure **102** may be, e.g., one or more of the resonant structures described in one or more of the related applications, each of which is described in greater detail above: U.S. application Ser. Nos. 11/243,476; 11/243,477; 11/238,991; 11/302,471; 11/325,432; 11/325,448; 11/325,571; and 11/325,534. In particular, the structure **102** may be one which emits light at a particular wavelength, e.g., visible light. Thus, the ultra-small resonant structure **102** emits an EMR wave (denoted W) in the waveguide layer **104**. The wave W may be modulated or otherwise manipulated to carry a data signal such as, e.g., a clock signal.

The waveguide layer **104** is preferably transparent at the wavelength of the EMR (light) emitted by the structure **102**. So, e.g., in the case of visible light, the waveguide layer **104** may comprise silica (silicon dioxide, SiO_2). Thus the wave W emitted by the structure **102** (and therefore the data signal in the wave) is carried throughout the waveguide layer **104**.

Various electronic circuits **108-1**, **108-2** (generally **108**) are formed on the transparent waveguide layer **104**. The various circuits **108** may each perform a different function and may be formed using known techniques. The invention is not limited by the nature of function of the circuits **108**. Each circuit **108** is operatively connected to the waveguide layer **104** so as to receive the wave W being carried in the layer (and thereby to receive any data signal—e.g., a clock signal—carried in the wave).

A circuit **108** may couple to the waveguide layer **104**, e.g., by forming a small defect in the layer in order to direct some of the light in the layer to the circuit **108**. Thus, e.g., as shown in the drawing, circuit **108-1** connects operatively to the waveguide layer **104** via defect **110-1**. A light detector (e.g., a CMOS detector) **112-1** couples light from the defect **110-1** to the circuit **108-1**. A similar structure may be used for the other circuit **108-2**.

As an alternative mode of connection, some or all of the circuits **108** may connect to the waveguide layer **104** using a detector such as, e.g., described, in related application Ser. No. 11/400,280, described in greater detail above and incorporated herein by reference.

Those skilled in the art will realize and understand, upon reading this description, that the substrate may be (or be formed on) a printed circuit board (PCB) or the like. Further, although only two circuits **108** are shown in the drawings, those skilled in the art will realize and understand, upon reading this description, that any number of circuits may be connected to the transparent layer in order to receive the same data signal in the wave W generated by the ultra-small structure **102**. The resonant structure **102** could be on top of or under the circuits and could be positioned anywhere in the waveguide.

As shown in FIG. **2**, the resonant structure **202** may be coupled to another device/circuit (denoted **C1** in the drawing) in order to provide a signal from that device to the other circuits **108**.

As noted above, the wave W may carry an encoded signal such as a clock signal. Thus, anywhere a clock signal is

required, it can be obtained via a connection (e.g., using a defect) to the waveguide layer.

Those skilled in the art will realize and understand, upon reading this description, that the waveguide layer covers a sufficient portion of the substrate to allow connection to all circuits formed thereon. In some cases, the waveguide layer may cover substantially all of the substrate.

Those skilled in the art will further realize and understand, upon reading this description, that more than one waveguide layer may be formed on a substrate, thereby allowing more than one data (e.g., clock) signal to be provided to different ones of the circuits formed thereon. Thus, as shown for example in FIG. **3**, a circuit **308** is operatively connected to each of two waveguide layers **304**-A, **304**-B. Ultra-small resonant device **302**-A emits EMR (e.g., visible light) at a wavelength W_A in waveguide layer **304**-A. Similarly, ultra-small resonant device **302**-B emits EMR (e.g., visible light) at a wavelength W_B in waveguide layer **304**-B. Each of the waveguide layers **304**-A, **304**-B is preferably transparent at the wavelength of the EMR (light) emitted by the corresponding structure **302**A, **302**-B, respectively. If the two waveguide layers **304**-A, **304**-B have contact locations (i.e., if they touch anywhere), then preferably the wavelengths emitted by the structures **302**A, **302**-B should be different.

The circuit **308** may connect to each waveguide layer in the manner described above. For example, as shown in FIG. **3**, the circuit **308** may connect to waveguide layer **304**-A via connection **310**-A and corresponding detector **312**-A, and similarly to waveguide layer **304**-B via connection **310**-B and corresponding detector **312**-B.

Although the various circuits are shown formed on the waveguide layer(s), those skilled in the art will realize and understand, upon reading this description, that only portions of the circuits need be formed on the waveguide layer(s) in order for the circuits to obtain data from the waveguide layer.

Methods of making a device for detecting an electromagnetic wave as can be employed herein may use the techniques described in related U.S. application Ser. Nos. 10/917,511 and/or 11/203,407, filed Aug. 15, 2005, entitled "Method of Patterning Ultra-Small Structures," each of which is described in greater detail above.

The devices described herein may also employ various similar or different example resonant structures to those described in one or more of the related applications, each of which is described in greater detail above: U.S. application Ser. Nos. 11/243,476; 11/243,477; 11/238,991; 11/302,471; 11/325,432; 11/325,448; 11/325,571; 11/325,534; and 11/400,280.

Although certain preferred embodiments and methods have been disclosed herein, it will be apparent from the foregoing disclosure to those skilled in the art that variations and modifications of such embodiments and methods may be made without departing from the spirit and scope of the invention. It is intended that the invention shall be limited only to the extent required by the appended claims and the rules and principles of applicable law.

GLOSSARY

As used throughout this document:

The phrase "ultra-small resonant structure" shall mean any structure of any material, type or microscopic size that by its characteristics causes electrons to resonate at a frequency in excess of the microwave frequency.

The term "ultra-small" within the phrase "ultra-small resonant structure" shall mean microscopic structural

dimensions and shall include so-called "micro" structures, "nano" structures, or any other very small structures that will produce resonance at frequencies in excess of microwave frequencies.

As the term is used herein, the structures are considered ultra-small when they embody at least one dimension that is smaller than the wavelength of visible light. The ultra-small structures are employed in a vacuum environment.

The invention claimed is:

1. A device comprising:

a waveguide layer formed on a substrate;

an ultra-small resonant structure constructed and adapted to emit electromagnetic radiation (EMR) in said waveguide layer;

one or more circuits formed on said waveguide layer and each operatively connected thereto to receive the EMR emitted by the ultra-small resonant structure.

2. A device as in claim **1** wherein the waveguide layer is transparent at wavelengths corresponding to wavelengths of the EMR emitted by the ultra-small resonant structure.

3. A device as in claim **2** wherein the EMR is visible light.

4. A device as in claim **1** wherein the ultra-small resonant structure emits EMR which encodes a data signal.

5. A device as in claim **4** wherein the data signal comprises a clock signal.

6. A device as in claim **1** wherein the ultra-small resonant structure is constructed and adapted to emit electromagnetic radiation (EMR) in response to excitation by a beam of charged particles.

7. A device as in claim **6** wherein the charged particle beam comprises particles selected from the group comprising: electrons, positive ions, negative ions, positrons and protons.

8. A device as in claim **6** further comprising:

a source providing a charged particle beam.

9. A device as in claim **8** wherein said source of charged particles is selected from the group comprising:

an ion gun, a tungsten filament, a cathode, a planar vacuum triode, an electron-impact ionizer, a laser ionizer, a chemical ionizer, a thermal ionizer, and an ion-impact ionizer.

10. A device as in claim **1** wherein the ultra-small resonant structure is constructed and adapted to emit at least one of visible light, infrared light, and ultraviolet light.

11. A method comprising:

providing a plurality of circuits operatively connected to a waveguide layer; and

emitting, by an ultra-small resonant structure, an electromagnetic signal into said waveguide layer, whereby said signal may be obtained by each of said plurality of circuits.

12. A method as in claim **11** wherein said signal encodes a clock signal.

13. A method as in claim **11** wherein said signal is encoded in visible light.

14. A method as in claim **11** wherein the ultra-small resonant structure is constructed and adapted to emit electromagnetic radiation (EMR) in response to excitation by a beam of charged particles.

15. A method as in claim **14** wherein the charged particle beam comprises particles selected from the group comprising: electrons, positive ions, negative ions, positrons and protons.

16. A method as in claim **14** wherein a source of said beam of charged particles is selected from the group comprising:

an ion gun, a tungsten filament, a cathode, a planar vacuum triode, an electron-impact ionizer, a laser ionizer, a chemical ionizer, a thermal ionizer, and an ion-impact ionizer.

17. A method as in claim **14** wherein the ultra-small resonant structure is constructed and adapted to emit at least one of visible light, infrared light, and ultraviolet light.

18. A method of providing a clock signal to a plurality of circuits, the method comprising:

providing a waveguide layer and operatively connecting each of the circuits to the waveguide layer; and

using an ultra-small resonant structure to emit an electromagnetic signal into said waveguide layer, whereby said signal may be obtained by each of said plurality of circuits, wherein said signal encodes a clock signal.

19. A method as in claim **18** wherein said signal is encoded in visible light.

20. A method as in claim **18** wherein the ultra-small resonant structure is constructed and adapted to emit electromagnetic radiation (EMR) in response to excitation by a beam of charged particles.

21. A method as in claim **20** wherein the charged particle beam comprises particles selected from the group comprising: electrons, positive ions, negative ions, positrons and protons.

22. A method as in claim **20** wherein a source of said beam of charged particles is selected from the group comprising:

an ion gun, a tungsten filament, a cathode, a planar vacuum triode, an electron-impact ionizer, a laser ionizer, a chemical ionizer, a thermal ionizer, and an ion-impact ionizer.

23. A method as in claim **20** wherein the ultra-small resonant structure is constructed and adapted to emit at least one of visible light, infrared light, and ultraviolet light.

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